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# Chapter 6.1

# Examining the impact of changing climate on regional air quality over the U.S.[☆]

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## 1. Introduction

QA :1

There is concern that global climate change over the next hundred years may lead to altered weather patterns that, along with changes in land use and source emissions could significantly impact tropospheric air quality. The U.S. Environmental Protection Agency (EPA)/National Oceanic and Atmospheric Administration (NOAA) Climate Impact on Regional Air Quality (CIRAQ) project assesses the impact of present-day and future (ca. 2050) climate on regional ozone and particulate matter ($PM_{2.5}$) in North America.

Downscaled regional climate conditions are derived from a global climate model (GCM) to define present and future climate scenarios. These regional climate scenarios are then used to drive the Community Multiscale Air Quality (CMAQ) model (Byun and Schere, 2006). In CIRAQ Phase I, anthropogenic emissions that do not directly respond to climate conditions are maintained at present levels in order to isolate the sensitivity of air quality to the climate scenario alone. CIRAQ Phase II will use alternative anthropogenic emission inventories that include future economic, population and technological change in the continental U.S.

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[☆] This work constitutes a contribution to the NOAA Air Quality Program. Although it has been reviewed by EPA and NOAA and approved for publication, it does not necessarily reflect their policies or views.

## 2. Development and analysis elements

The CIRAQ project involves the development and analysis of: (1) a decade of present-day (ca. 2000) and future (ca. 2050) regional climate model (RCM) data; (2) 5 years of present and future climate driven emission scenarios and (3) 5 years of present and future CMAQ simulations. Each is discussed below.

### *2.1. Regional climate scenarios*

#### *2.1.1. Description*

The NASA Global Institute for Space Studies (GISS) version II GCM (Rind et al., 1999) was run assuming the IPCC SRES A1B global emissions scenario. Regional air quality models require information at finer horizontal and vertical resolutions than is typically available from GCM simulations. The Fifth Generation Pennsylvania State University/National Center for Atmospheric Research Mesoscale Meteorological Model (MM5; Grell et al., 1994) was used to generate physically consistent downscaled regional climate scenarios (MM5/RCM) from the coarse GCM data over a 36 km × 36 km gridded domain (e.g., Fig. 1). These downscaled simulations do not necessarily reproduce day-to-day and year-to-year observed variations but rather, they represent climatological time periods under specified greenhouse gas forcing. Without the assimilation of observed data to constrain the GCM and mesoscale models, careful evaluation against observed climate conditions is essential to identify meteorological biases in the downscaled data that will impact CMAQ model predictions.

#### *2.1.2. Results*

Ten years of MM5/RCM downscaled summer season mean sea-level pressure and 2 m temperature data at 1800 UTC representing current climate have been compared to gridded North American Regional Reanalysis (NARR; Mesinger et al., 2006) data from 1996 to 2005. Mean summer NARR and MM5/RCM sea-level pressure patterns (Fig. 1) compare well along and off the western coast and across the southwestern U.S., indicating the MM5/RCM is simulating the dominant synoptic flow pattern correctly. The MM5/RCM also correctly simulates higher pressure over the eastern U.S. and lower mean pressure over the western U.S.

QA :2

Conversely, the mean NARR pattern indicates the presence of a persistent sub-tropical high-pressure system off the eastern U.S. coastline

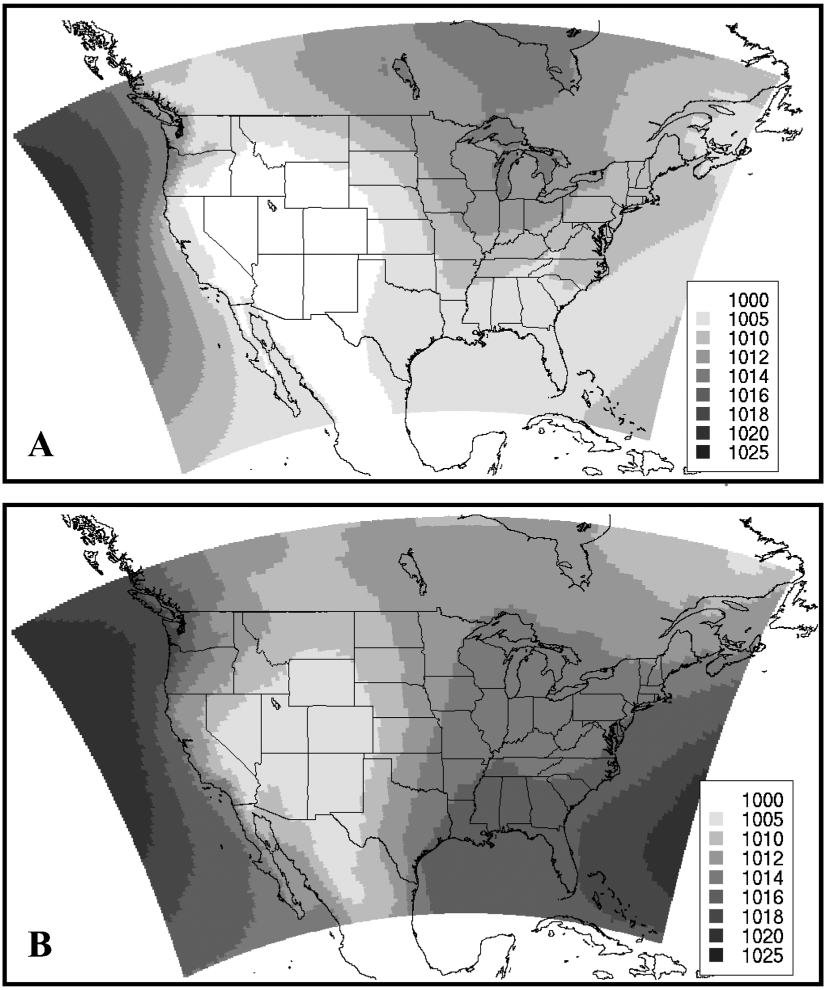

*Figure 1.* Summer (JJA) mean sea-level pressure anomalies (mb) for (A) MM5/RCM and (B) NARR.

that is absent in the MM5/RCM data. The MM5/RCM also erroneously simulates low pressure in the Gulf of Mexico and just off the eastern U.S. coast, and increasing mean pressure from the Mississippi River Valley northward to the Great Lakes and Canada. Spatial patterns of simulated current and future MM5/RCM mean sea-level pressure (not shown) are in general agreement for the summer period.

Surface temperatures have been shown to correlate well with ambient concentrations of several common pollutants, e.g., ozone. MM5/RCM 2 m summertime temperatures in the northeastern U.S., Florida and southern Texas are up to 3 K cooler on average than the NARR (Fig. 2). The cooler temperatures over Texas and Florida seem related to increased afternoon cloudiness. Cooler conditions in the northeastern U.S. are related to the MM5/RCM dominant high pressure located over the Great Lakes and Ohio River Valley, resulting in dominant northerly flow and cooler afternoon temperatures. The MM5/RCM is 7–9 K cooler than the NARR pattern over the upper Great Plains. Isolated areas of very large temperature differences along the western U.S. coast and Rocky Mountains are most likely interpolation artifacts and should be ignored.

Future period summertime MM5/RCM 2 m temperature simulations average 2–3 K warmer across much of the southwestern U.S., Rocky Mountains and the Pacific Northwest. Over the eastern U.S., the future summer climate is an average of 1 K warmer. Areas of the central and northern U.S. are less than 0.5 K warmer in the future simulation.

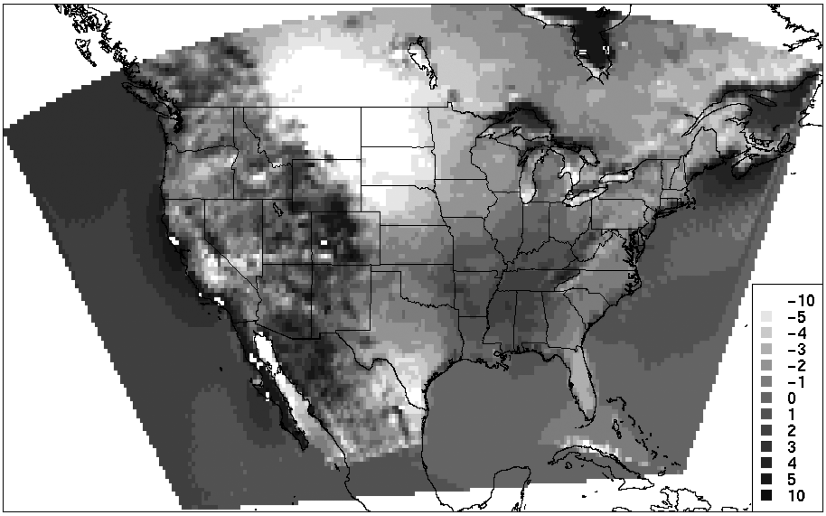

*Figure 2.* Difference (K) in the mean summer (JJA) 1800 UTC 2 m temperature between the MM5/RCM and the NARR (computed as MM5/RCM-NARR).

## 2.2. Emissions scenarios

### 2.2.1. Description

The current emission inventory is represented by version 2001ad of the 2001 National Emission Modeling Inventory (U.S. Environmental Protection Agency, 2004). Biogenic and mobile source meteorologically dependent emissions and plume rise are modeled using the same MM5/RCM data analyzed in Section 2.1. The biogenic emissions are modeled using Biogenic Emission Inventory System (BEIS) version 3.13 and on-road mobile source emissions are modeled by the U.S. EPA MOBILE6 model.

### 2.2.2. Preliminary results

Analysis of meteorologically influenced emission rates during 5 years of current-period downscaled data shows peak isoprene emission fluxes are an order of magnitude greater and more variable in the eastern U.S. than in the West (Benjey and Cooter, 2005). Biogenic NO emission rates follow the same spatial and temporal trends, but are less variable. On-road mobile source emissions (principally $NO_x$ and $PM_{2.5}$) are higher in the East, but exhibit less temporal and spatial variability because of the effects of non-meteorological variables and temperature averaging in the MOBILE6 model.

Modeled emission rates for 5 years of future-period downscaled data (Table 1) identify larger and more variable isoprene and NO emission fluxes that reflect the general increase in 2 m temperature signal (see Section 2.1.2). Future median isoprene values are 21% (West) and 43% (East) greater than current rates. Figure 3 shows that increase in emission rates and their associated interquartile ranges are focused on the spring and summer seasons. The pattern of change for biogenic NO emission rates is similar, but of lesser magnitude.

Modeled mobile source emissions, as represented by $NO_x$ and $PM_{2.5}$ emission rates, change relatively little between the current and future periods (Table 1). There is little change between seasons or years due to meteorology. This lack of response is likely a product of the limited sensitivity to temperature of the MOBILE6 model with respect to the other model input variables and temperature averaging.

*Table 1.* Annualized statistics of area-weighted (eastern/western region) mean hourly meteorologically influenced current and future emission rates reported as kg $year^{-1}$ $km^{-2}$

| | Minimum | | Median | | Maximum | | Interquartile Range | |
|---|---|---|---|---|---|---|---|---|
| | C | F | C | F | C | F | C | F |
| Isoprene—Eastern U.S. | 0.0 | 0.0 | 8.0 | 11.4 | 10,915.2 | 11,408.5 | 463.2 | 654.1 |
| Isoprene—Western U.S. | 0.0 | 0.0 | 2.7 | 3.4 | 3474.0 | 4717.8 | 132.5 | 192.1 |
| Biogenic NO—Eastern U.S. | 0.0 | 0.0 | 60.8 | 68.4 | 202.5 | 228.0 | 61.8 | 63.4 |
| Biogenic NO—Western U.S. | 0.0 | 0.0 | 29.0 | 33.7 | 77.5 | 79.5 | 31.4 | 32.5 |
| Mobile $NO_2$—Eastern U.S. | 4.9 | 4.8 | 23.6 | 23.9 | 53.6 | 54.1 | 24.6 | 24.8 |
| Mobile $PM_{2.5}$—Eastern U.S. | 0.9 | 0.9 | 9.3 | 9.5 | 20.5 | 20.5 | 10.5 | 10.6 |

C, represents the 5-year current period; F represents the 5-year future period.

## 2.3. Air quality scenarios

### 2.3.1. Description

The air quality modeling scenarios are generated using the U.S. EPA CMAQ model, version 4.5 (Byun and Schere, 2006). The horizontal model domain covers the contiguous U.S. at a 36 km grid resolution. Current and future simulations are 5 years each in length to account for interannual variability. Chemical boundary conditions were obtained from global chemical transport models (CTMs) driven by the same GCM used to drive the MM5/RCM downscaling (Section 2.1). Initial and domain boundary conditions for ozone, $NO_x$ and VOC species concentrations were obtained from Mickley et al. (1999), while aerosol species concentrations were computed from the unified tropospheric chemistry-aerosol model of Liao et al. (2003). Evaluation of a related global CTM at this spatial scale, i.e., $4^\circ \times 5^\circ$, has shown spatial prediction patterns that were quite good but local maxima that were compromised (Fiore et al., 2003). Since we are using the global CTM predictions as background monthly average values, the coarse resolution should be sufficient. Preliminary results for ozone and $PM_{2.5}$ are presented here; more complete analyses, including a comparison with the results of Hogrefe et al. (2004), will be presented in a forthcoming paper.

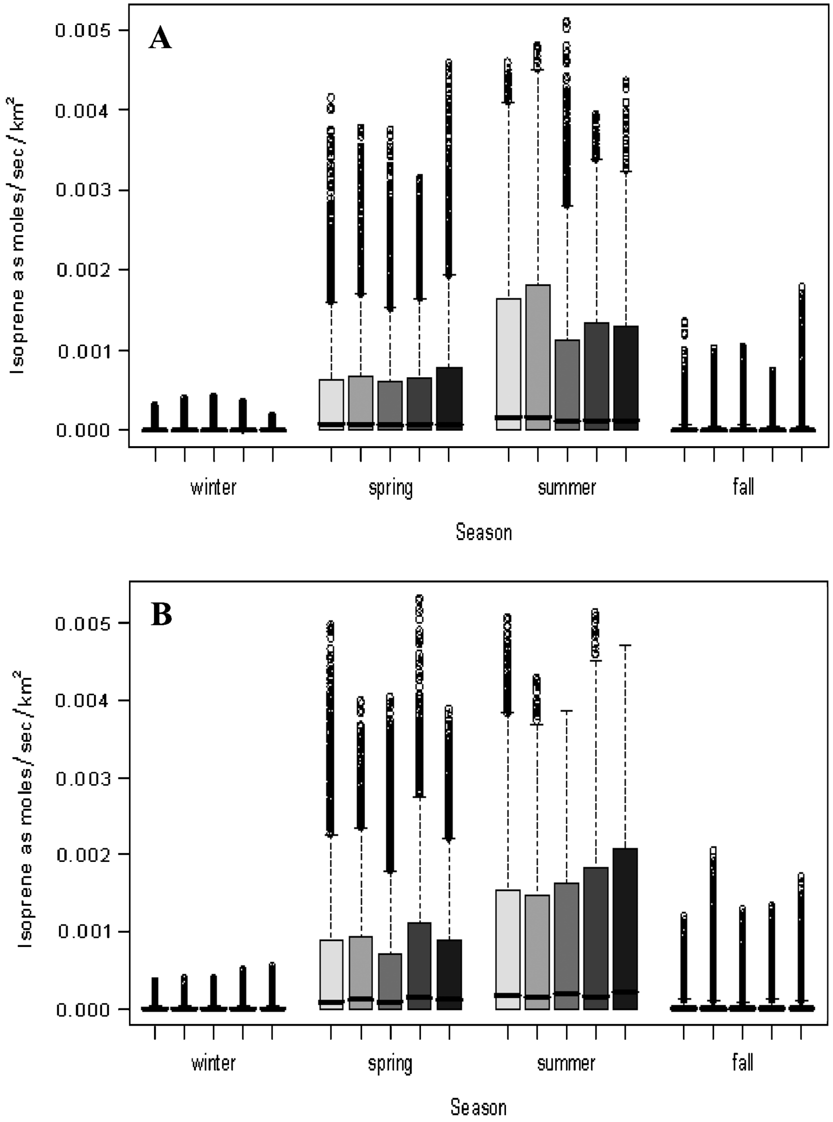

*Figure 3*. Box plots of (A) current period and (B) future period seasonal isoprene emission rates for the eastern U.S. The vertical bars define the interquartile range (IQR). The horizontal bars mark the median. The vertical dashed line represents the upper range of emission rates (1.5 times the IQR). The small circles represent outlier values.

### *2.3.2. Preliminary results*

Surface-level ozone concentrations are of concern primarily during the summer months. Empirical cumulative distribution functions (CDFs) of maximum 8-h average ozone concentrations for June 1–August 31 of each current and future year simulated are plotted in Fig. 4. Future summer season ozone concentrations in the northeastern U.S. show no significant

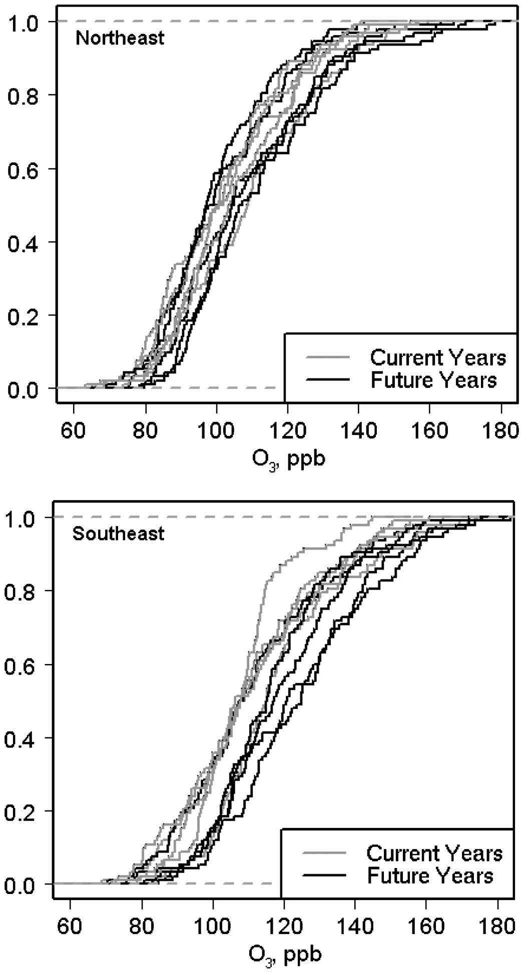

*Figure 4.* Empirical CDFs of modeled maximum 8-h average surface ozone concentration (ppb) June 1–August 31 for five current and five future downscaled climate years for the northeastern and southeastern U.S.

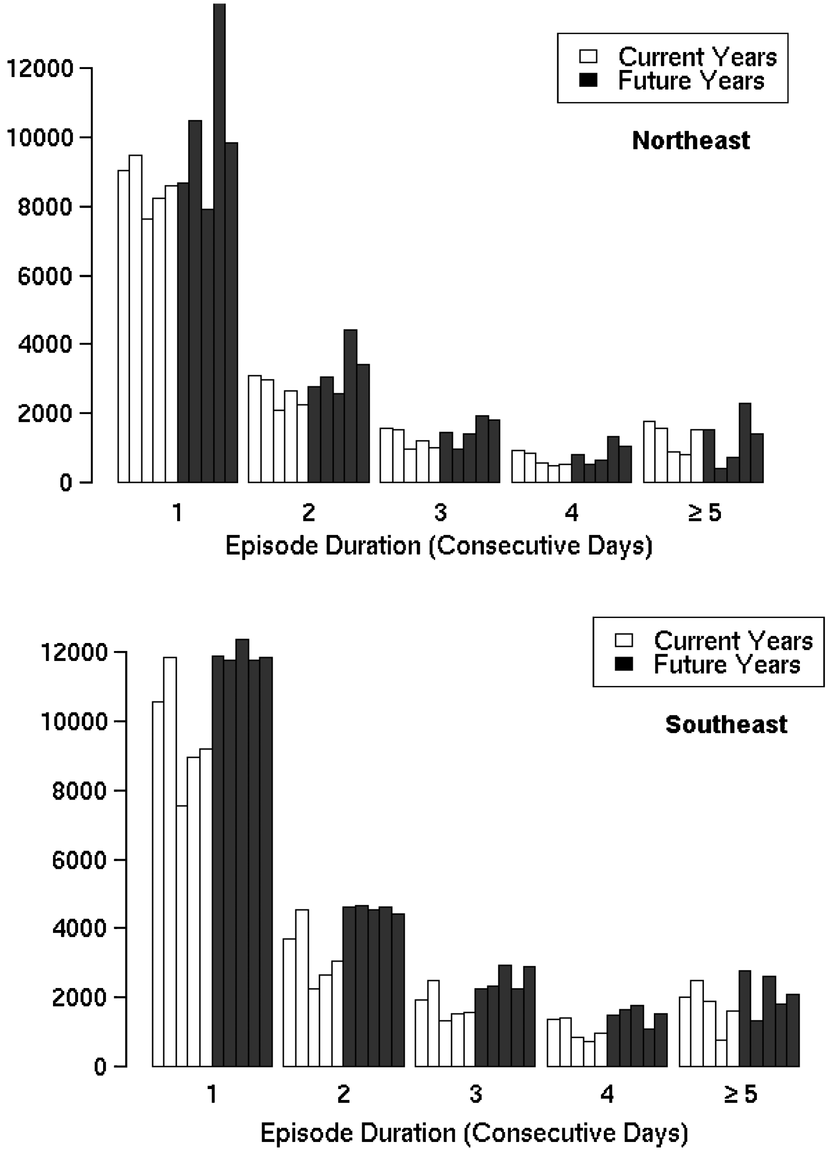

*Figure 5*. Domain-wide frequency and duration of events during which modeled peak 8-h ozone concentrations exceeded 80 ppb during five current and future downscaled climate years for the northeastern and southeastern U.S.

change from current period simulations. Simulated future concentrations in the southeastern and western (not shown) U.S. are higher (shifted right) than current period estimates. Figure 5 shows a comparison of the frequency and duration of $O_3$ episodes (defined as grid cells where 8-h maximum concentrations exceeded 80 ppb). Again, future simulations in the northeastern U.S. show little change from the current period, but the

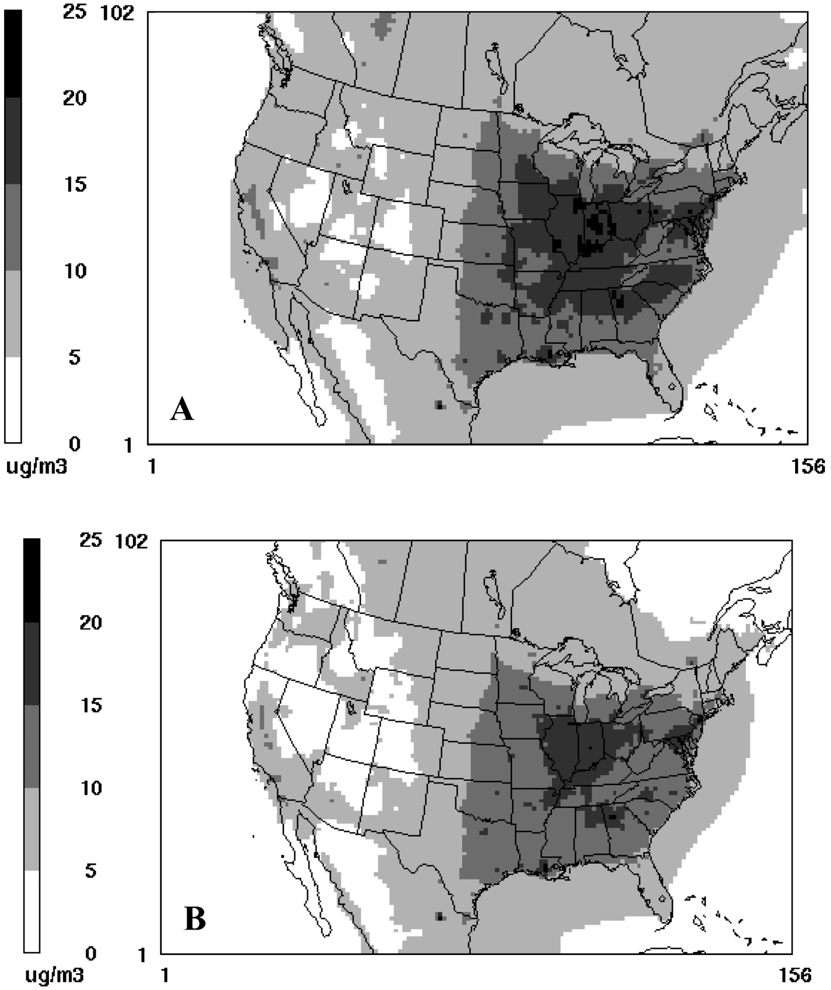

*Figure 6.* Annual average $PM_{2.5}$ concentrations ($\mu g\,m^{-3}$) for (A) current and (B) future downscaled climate years.

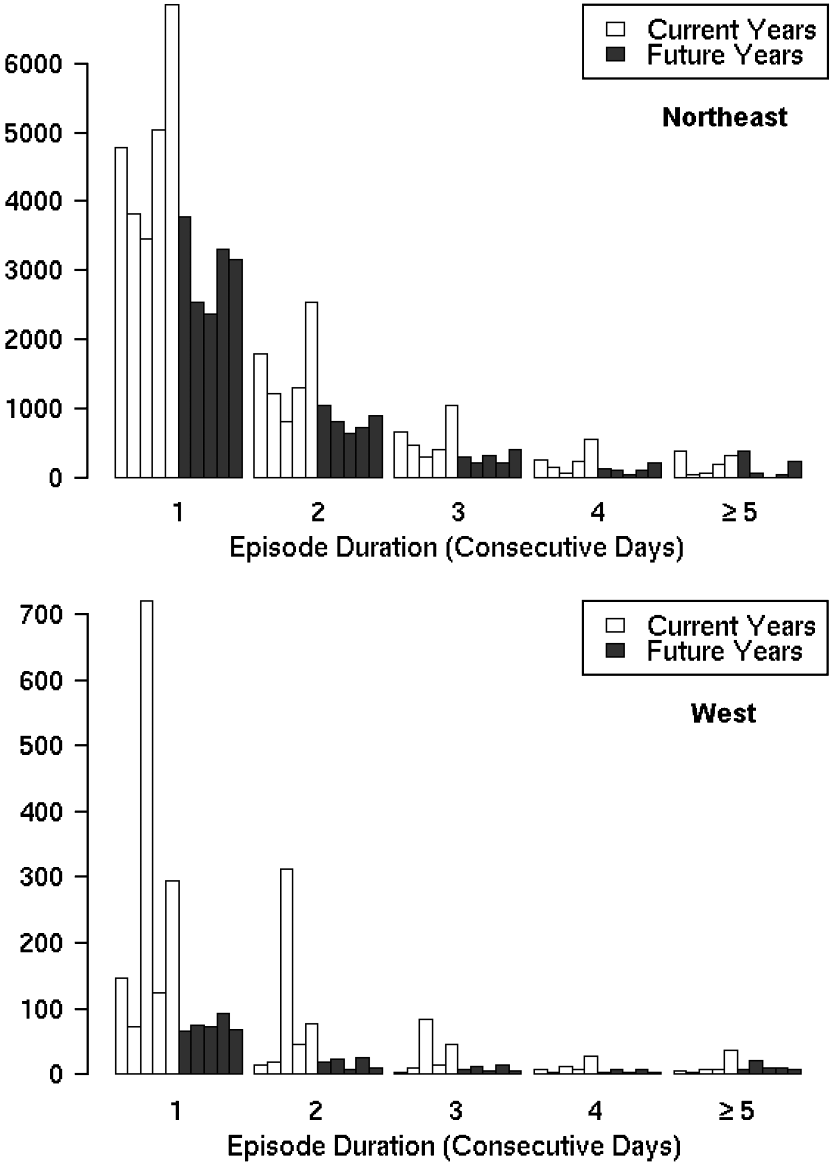

*Figure 7.* Domain-wide frequency and duration of days during which modeled 24-h average $PM_{2.5}$ concentrations exceeded $35\,\mu g\,m^{-3}$ during five current and five future downscaled climate years for the northeastern and western U.S.

frequency and duration of these events increase in the southeastern and western (not shown) U.S. data.

Although average annual concentrations of future $PM_{2.5}$ concentrations are somewhat lower than the current period, the spatial patterns are quite consistent (Fig. 6). Future frequency and duration of 24-h average $PM_{2.5}$ concentration episodes, which exceed $35\,\mu g\,m^{-3}$ are reduced from those of the current period data. The differences in $PM_{2.5}$ are likely resulting from differences in transport or other meteorological factors. The specific causes are currently under investigation (Fig. 7). QA :3

## 3. Summary

Climate analysis results for the current (ca. 2000) summer season indicate that the MM5/RCM does not replicate the dominant summer weather pattern off the eastern portion of the continental U.S. domain. Although general weather patterns change little in the future (ca. 2050), 2 m temperatures are on average 2–3 K warmer over the southwest quadrant of the U.S. Other regions of the U.S. are also warmer, but generally by less than 1 K. A preliminary comparison of modeled current to future biogenic and mobile emission rates reflect expected geographic and interannual variability and a general increase in biogenic emissions in response to warmer future temperatures. Preliminary air quality modeling results identify regional differences in the response of current simulated 8-hour maximum ozone concentrations to future climate change ranging from no difference (northeastern U.S.) to increased concentrations (southeastern and western U.S.). Annual average particulate matter concentrations and the frequency and duration of elevated particulate matter episodes decrease in the future period relative to current period simulations.

## Discussion

| | |
|---|---|
| A.-L. Norman: | The decrease in $PM_{2.5}$ with climate change is counterintuitive—is it related to decreases in sulphate? |
| E.J. Cooter: | The decrease in $PM_{2.5}$ is not due to changes in sulfate emissions, because anthropogenic emissions are held constant in these simulations. The decrease is evident in all components of PM and is not specific to sulfate. We suspect the decrease is due to a combination of |

increased precipitation and changes in ventilation, but cannot say for certain as yet. We hope to answer this question more definitively after further analysis.

A. Ebel: How are land surface changes treated in the emission scenario simulations?

E.J. Cooter: Land cover (type) and land use is held constant at current conditions in the results reported here. A Phase II study will begin shortly that will include alternative anthropogenic emission futures. We have the capacity to include appropriate population and/or economically driven land cover and land use changes associated with those future scenarios if they are provided to us.

D.W. Byun: One statement you have made is that the regional climate model may not inherit the features of the global climate model due to the problem of downscaling. When we tested downscaling, depending on the method used, sometimes the regional model was “blind” to the change in the global model simulations. What do you do to ensure the climate change is still well presented during the downscaling?

E.J. Cooter: Dr. Ruby Leung of the DOE Pacific Northwest National Laboratory generated our downscaled climate data using a regional climate version of MM5. Her previous experience working with the PCM Global Climate Model suggested an initial set of mesoscale model parameterizations that would best preserve the large-scale global model results. Testing prior to the final production runs indicated changes were needed to the westward domain extent of the coarse 108 km rectangular mesoscale grid, increasing it from 67 × 89 grid points to 67 × 109 grid points. An alternative convection parameterization scheme (switch from Kain-Fritsch to Grell) was needed to preserve the NASA/GISS II’ model solution. It is important to note that a conscious decision was made to preserve the large-scale global model information, even if that meant poor or degraded performance relative to the observed present-day climate.

## ACKNOWLEDGMENTS

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